A vertical photograph on the left side of the slide showing an industrial facility at night. The facility is brightly lit with numerous lights, and smoke is visible rising from the chimneys against a dark sky.

Decarbonizing Chemicals and Other Industries in Louisiana

For the Louisiana Climate Task Force
Friday, Oct. 8, 2021

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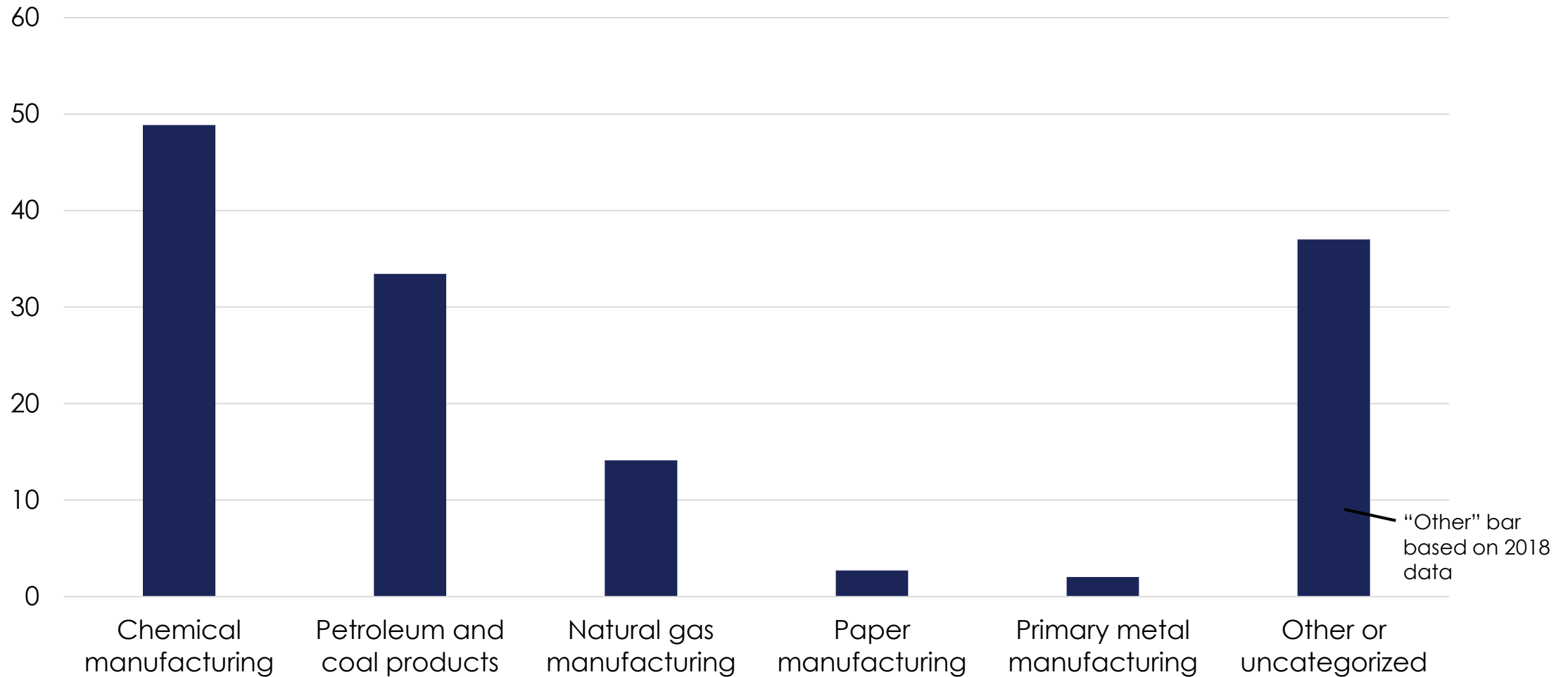


Presentation Overview

- **The Chemicals Industry**
 - *Emissions sources and processes*
 - *Decarbonization technologies and technical approaches*
- **Policies to Decarbonize Industry**
 - *Not only for the Chemicals industry*
 - *Overview of key policy measures, with a focus on many in Louisiana's Climate Action Plan*



Louisiana Industrial GHG Emissions by Industry in 2019 (MMT CO₂e)



Source: David E. Dismukes, Louisiana State University Center for Energy Studies, Louisiana 2021 GHG Inventory: Update and summary of preliminary findings (slides 29-30), 7/29/2021, https://gov.louisiana.gov/assets/docs/CCI-Task-force/JuneMtgs/GHG-INVENTORY_FINAL-DRAFT-REPORT_CTF_final.pdf

The Chemicals Industry

▪ Basic Chemicals

- *Petrochemicals*
- *Some petrochemical products, such as plastic resins and synthetic fibers*
- *Inorganic basic chemicals (sulfuric acid, sodium hydroxide, chlorine, industrial gases, etc.)*

▪ Agricultural Chemicals

- *Fertilizers*
- *Pesticides, herbicides, etc.*

▪ Specialty Chemicals

- *Paints, water treatment chemicals, adhesives, fuel additives, etc.*

▪ Consumer Products

- *Personal care products, soaps/detergents, fragrances, etc.*

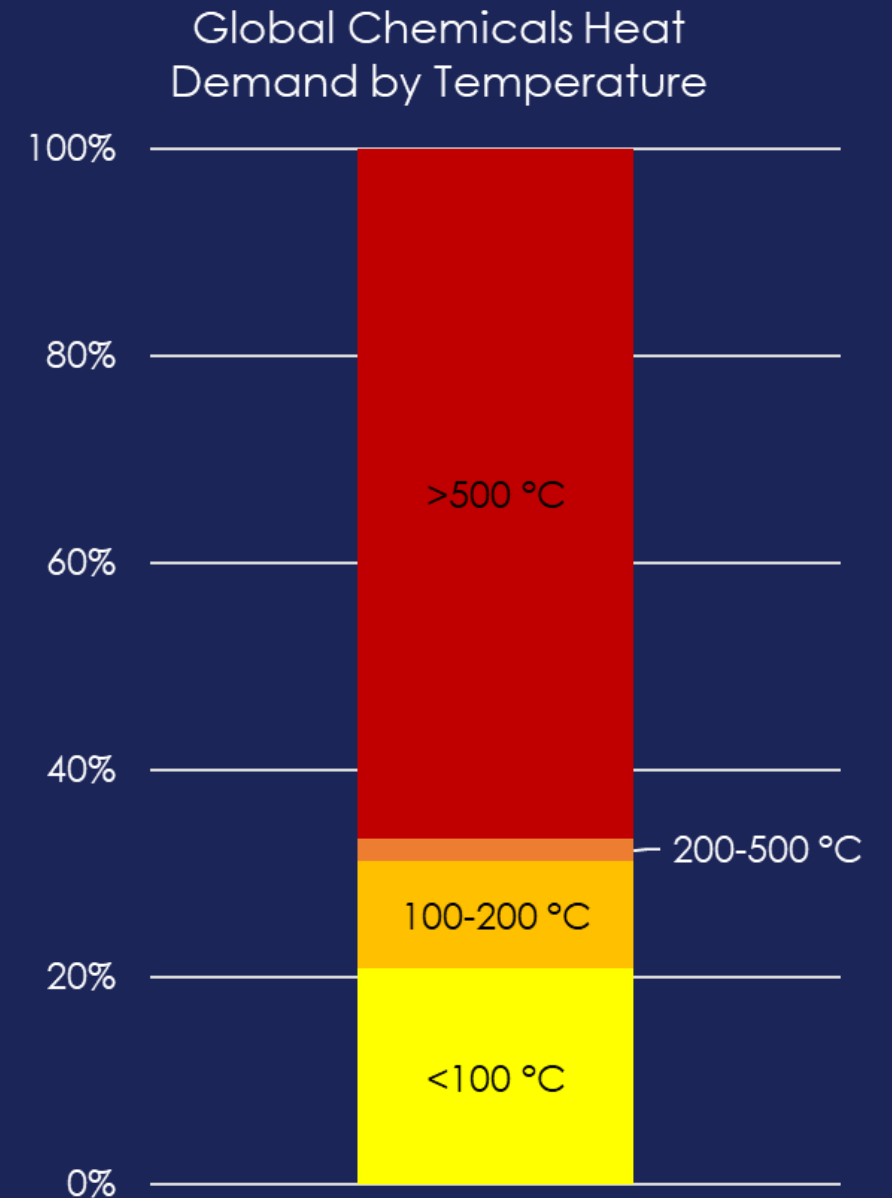


Petrochemicals: Key Chemical Building Blocks

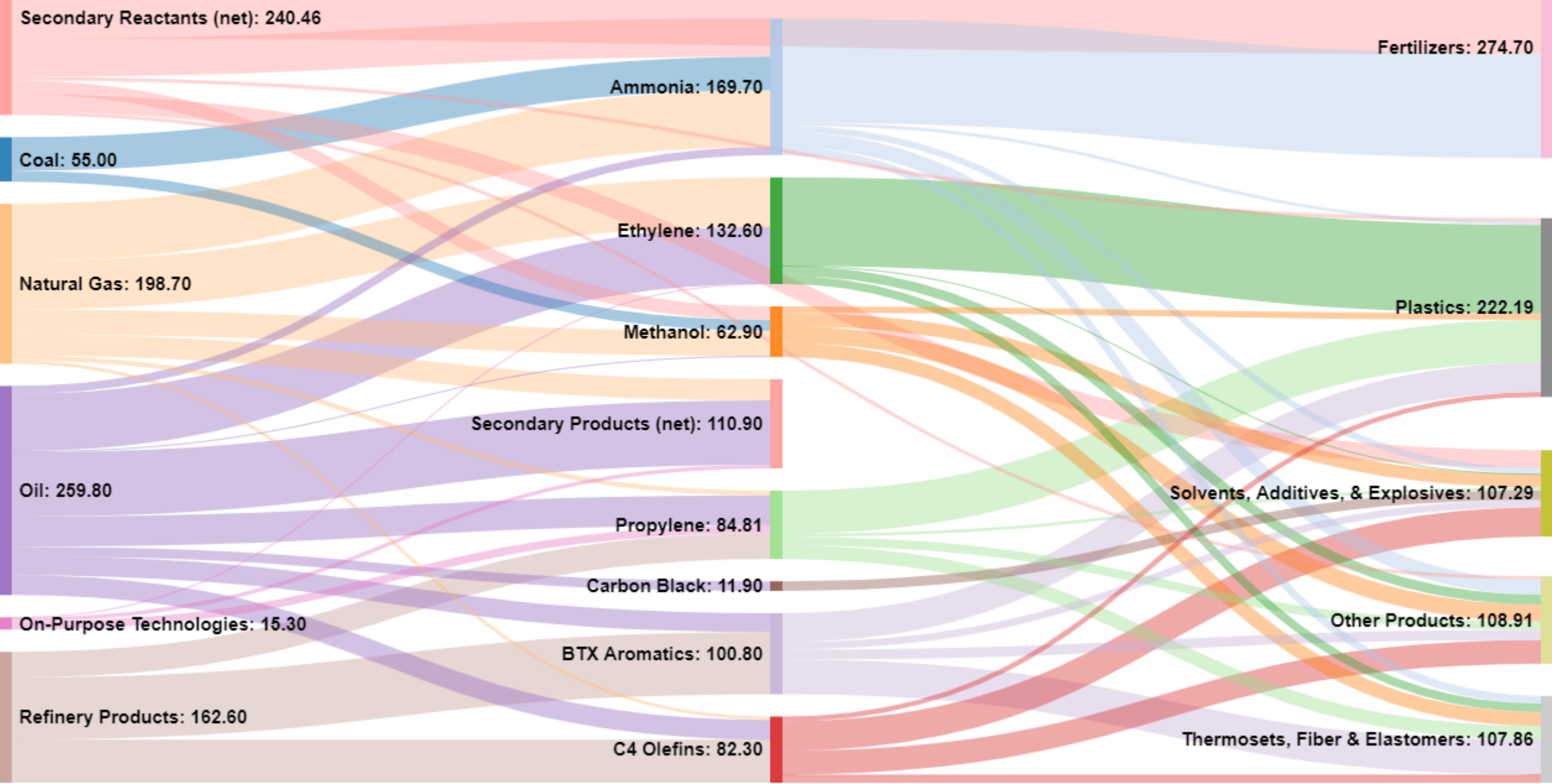
Petrochemical	2013 Global Production (Mt)	Example Uses
Ammonia	169.7	fertilizers, cleaners
Methanol	62.9	plastics, plywood, paints, explosives, antifreeze
Light Olefins (ethylene & propylene)	217.4	plastics
BTX Aromatics (benzene, toluene, xylenes)	100.8	plastics, adhesives, solvents
C4 Olefins (butadiene, butenes)	82.3	rubber, plastics, fuel additives
Carbon Black	11.9	tires, black pigment

Fuels as Chemical Feedstocks

- Fuels are used for two purposes by the chemicals industry
- **41% are burned for heat and power** (global figure)
- **59% are chemical feedstocks** (global figure)
 - *Feedstock fuels are physically transformed into products (petrochemicals and petrochemical products), not burned for energy*



Global Use of Fossil Feedstocks to Make Petrochemicals and Final Products (MMT)



Why Decarbonize Feedstocks?

1. To Stop CO₂ Process Emissions

- 15% of chemicals industry CO₂ emissions (0.2 Gt/yr) are process emissions.
- This is the difference between carbon in the feedstocks and carbon in the final products, after any use of recovered CO₂ (e.g. carbon from making ammonia used to make methanol)

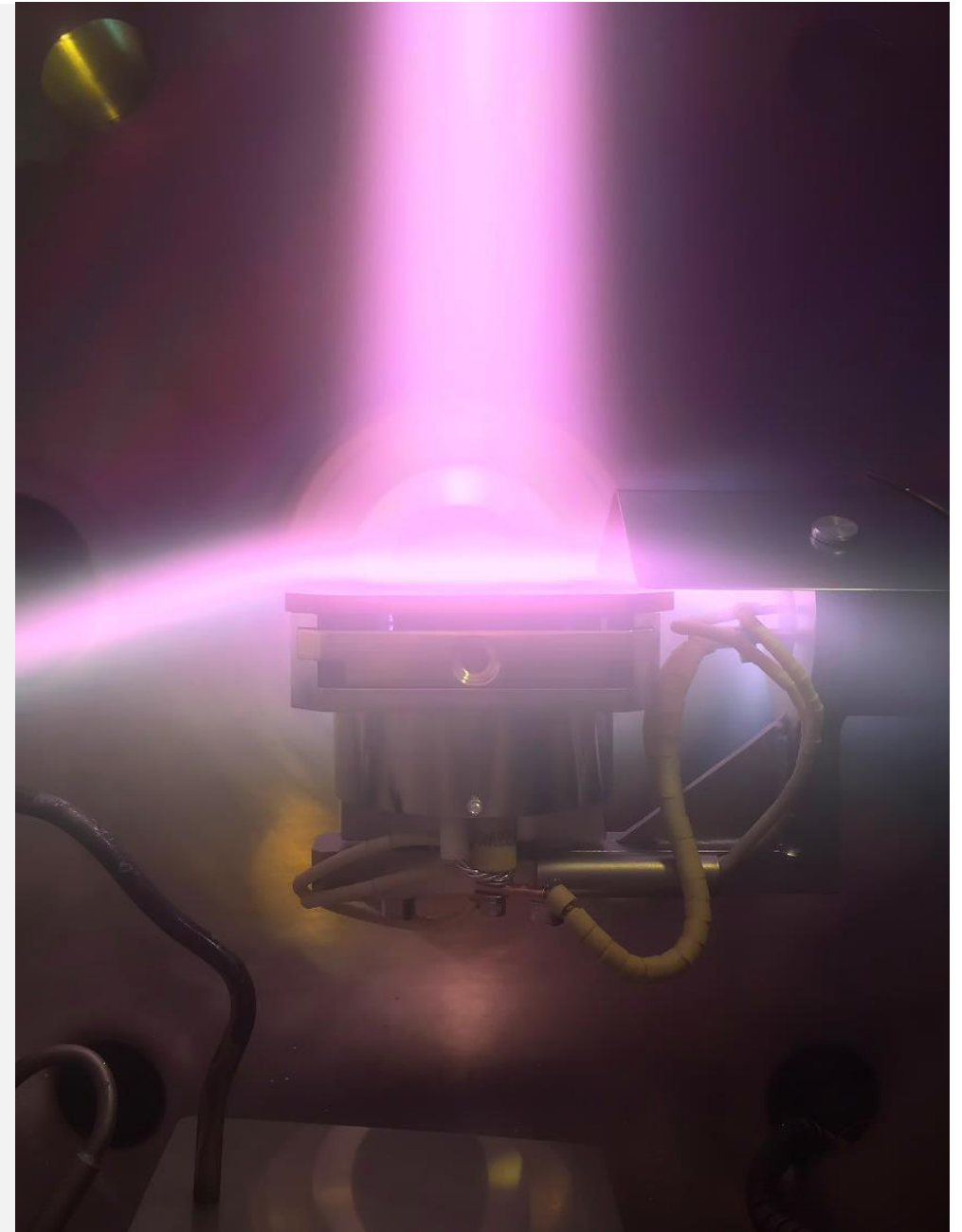
2. Chemical products are not intended to be long-term stores of carbon

- Fertilizers, fuel additives, etc. release their carbon when the product is used
- Most plastics reach end-of-life within a few years. 16% are incinerated (projected to rise to 50% by 2050)
- Products released into environment break down in years to centuries



Hydrogen + CO₂ as Feedstock

- Use electrolysis (with zero-carbon electricity), methane pyrolysis, or another technique to generate clean hydrogen
- Obtain CO₂ from combustion, from other chemical transformations, or from another industry (e.g., cement)
- Key challenge: Capital and electricity costs of zero-carbon hydrogen.



Hydrogen + CO₂ to Petrochemicals

- **Ammonia** Commercialized
 - Typically made via the Haber process, using H₂ + N₂, so green hydrogen is a drop-in substitute in current processes
- **Methanol** Early Commercial
 - Formation uses a similar pathway to fossil-derived methanol ($3\text{H}_2 + \text{CO}_2 \rightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O}$), so relevant technology and catalysts are already commercialized
 - There already exist roughly 10 operating methanol plants using electrolytic hydrogen + CO₂
- **Light Olefins, C4 Olefins, and BTX Aromatics**
 - May be created from green methanol
 - China already commercialized methanol-to-olefin processes, since this pathway is also involved in making chemicals from coal gasification Commercialized
 - Methanol-to-aromatics production routes are in the demonstration stage Demonstration Phase



Lego bricks are made from butadiene, a petrochemical

Biomass as Feedstock

- **Ethylene can be derived from ethanol.**
 - *Brazil converts some sugarcane ethanol to ethylene today*
- **Methanol can be derived from biomass gasification**
- **Olefins and aromatics can be derived from methanol (as noted above)**
- **Carbon black can be replaced by chemicals from agricultural or food wastes**
- **Key challenges:**
 - *High capital costs to for equipment to process biomass. For example, equipment to make ammonia from biomass costs 7x as much as equipment to make ammonia from natural gas*
 - *More impurities, purification steps, energy use, and potentially, local air pollutants*
 - *Biomass growth has its own impacts and sustainable supply is limited*

Demonstration Phase

Commercialized

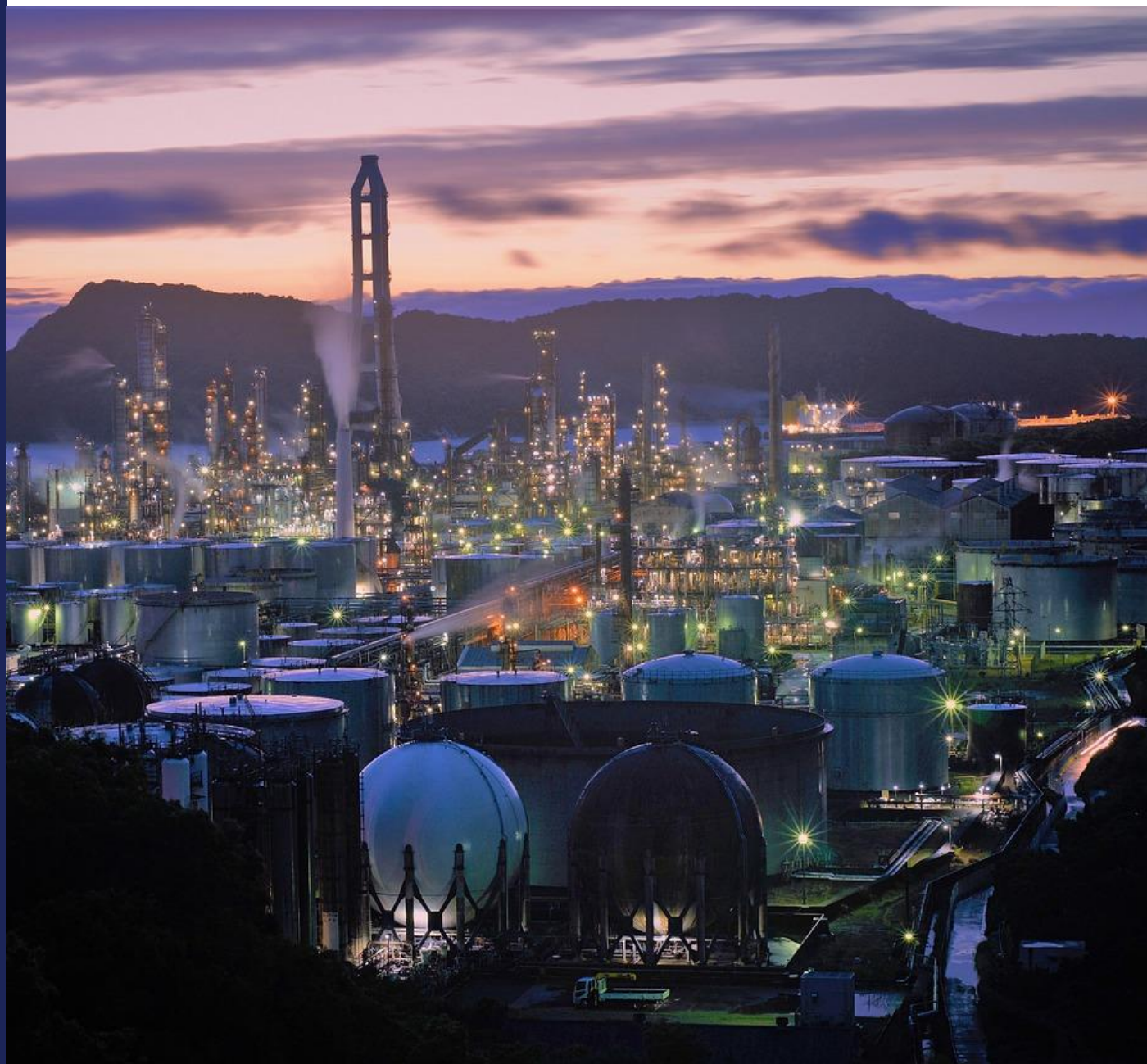
R&D Phase



Non-Feedstock Energy Use

- 41% of chemicals industry energy use globally is for heat and power, not feedstocks

Energy Source	Global Chemicals Non-Feedstock Energy Use (%)
Natural gas	29%
Purchased electricity	23%
Coal	23%
Petroleum	13%
Purchased heat/steam	12%
Bioenergy	<1%



Strategies Useful for Many Industries, Not Only Chemicals

- **Electrification of heat**

- *Low temp (<150 C) – industrial heat pumps* Commercialized
- *Medium temp (150-500 C) – electric resistance, dielectric heating, infrared heating, etc.* Commercialized
- *High temp (500+ C) – induction, electric arcs, lasers*
 - For metals Commercialized
 - For non-metals R&D Phase

- **Combustion of green hydrogen, hydrogen-derived fuels, or bioenergy** Demonstration Phase

- **Carbon capture** Early Commercial

- These are all important, but this presentation focuses on strategies specific to the Chemicals industry



Industrial boiler

Electrified Steam Cracking

R&D Phase

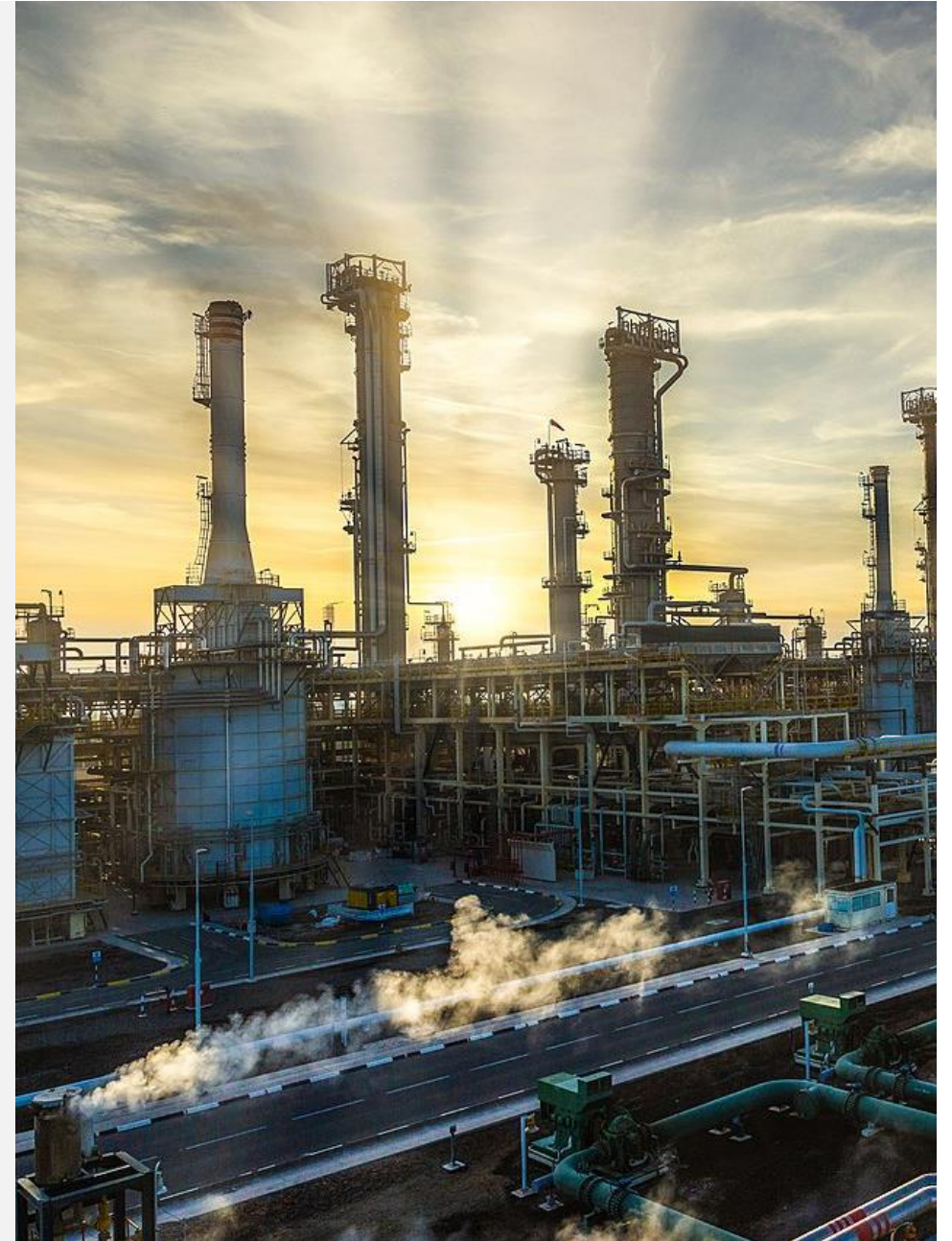
- A steam cracker breaks large hydrocarbon molecules into small ones in the presence of steam
 - Operates at over 800 °C
 - \$2 billion to construct
- A consortium of six chemical companies is working to develop electrified steam crackers, aiming to have a pilot operating by 2030
 - BASF, Borealis, BP, LyondellBasell, Sabic, and Total



Improved Catalysts and Catalytic Cracking

Early Commercial

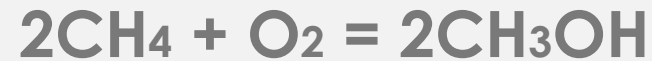
- Catalysts accelerate a reaction by lowering activation energy barrier. They can allow reactors to run at lower temperatures, reducing energy requirements, and can improve product yield.
- Many downstream processes = many opportunities for catalysts
- Most important opportunity to use catalysts for energy savings is catalytic cracking of hydrocarbons. First plant began operation in South Korea in 2017. Operates at 600-650 °C instead of >800 °C and has 30% improved light olefin yield.



Methanol from Partial Oxidation of Methane

R&D Phase

- Traditional methanol production requires steam methane reforming, converting CH_4 to a mix of H_2 , CO , and CO_2 . Then, this syngas mixture is pressurized and converted to methanol using catalysts.
- An alternative route involves reacting methane with oxygen directly, e.g.



- This avoids the need to first produce syngas, the process step responsible for 60% of the capital costs and 45-70% of the net energy consumption (i.e., excluding the energy in the produced methanol)
- Faces challenges such as reducing cost of obtaining purified oxygen as an input and avoiding oxidation of the produced methanol, which creates unwanted CO or CO_2 .
- BASF and Linde Engineering plan to have a large-scale plant running by 2030



Methanol distillation

Non-CO₂ Process Emissions

▪ Fluorinated gases (F-gases)

- Most produced intentionally, to use as a refrigerant, aerosol propellant, electrical insulator, etc.
- Replace with climate-safe substitutes, recover and destroy F-gases at end of product life

Early Commercial

▪ Nitrous Oxide (N₂O)

- 75% is a byproduct of producing just two chemicals: nitric acid and adipic acid
- Up to 98% can be destroyed at low cost using already-commercial technologies

Commercialized

▪ Methane

- Mostly leaks from natural gas lines/equipment and from fertilizer plants
- Monitor and control leaks

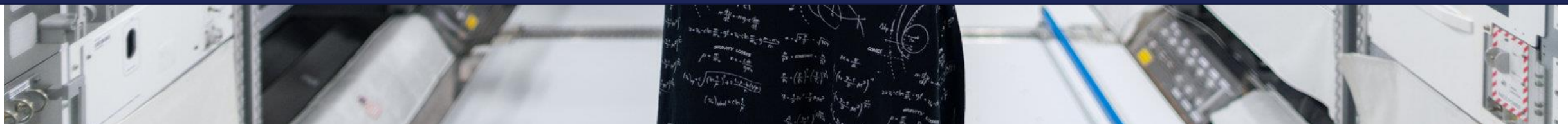
Commercialized



Nylon, a product made from adipic acid



Policies for Industrial Decarbonization



Overview of Policies to Decarbonize Industry

▪ Financial Policies

- Carbon pricing (carbon tax or cap-and-trade)
- Green banks and revolving funds
- Tax breaks, cost sharing, and loan guarantees for innovative processes and pilot projects

▪ Policies to Promote Research & Development (R&D)

- Public-private research partnerships, national labs
- Financial incentives for R&D (tax credits, grants, contract research)
- Policies ensuring access to workers with science, technology, engineering, and mathematics (STEM) skills

▪ Performance Standards

- Emissions standards
- Energy efficiency standards
- Material efficiency and quality standards (e.g., for buildings and infrastructure)

▪ Other Policies

- Green government procurement (i.e., Buy Clean)
- Product labeling requirements
- Emissions audit and disclosure requirements
- Circular economy support policies (repairability, take-back, recycling)



Thank You

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